Single Gun, Multiple Round, Time-on-target Capability for Advanced Towed Cannon Artillery

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At the request of the Advanced Towed Cannon System (ATCAS) Program Manager, the U.S. Army Research Laboratory conducted a study that addressed the technical feasibility of a single gun, multiple round, time-on-target (TOT) capability for advanced towed cannon artillery. The study was conducted under the ATCAS test bed program created to conduct studies and tests to support the rationale for the joint operational requirements document for a new lightweight, towed, 155mm howitzer for the U.S. Army and U.S. Marine Corps. Rate of fire, projectile loading restrictions, and projectile mix within a fire mission were varied to determine the maximum benefit to the single gun, multiple round, TOT capability. With a tube elevation rate of 30 mils per second and a capability to load at all elevations, a towed howitzer can achieve a four-round TOT capability at 65% of the 20 1-kilometer range intervals between 5 and 24 kilometers when firing the M107 or M549A1 (rocket on) within a given fire mission. A towed howitzer with the same elevation and loading capabilities plus the ability to shoot a mixture of M107 and M549A1 (rocket on) within the same mission can achieve a four-round TOT capability at 75% of the range intervals between 5 and 24 kilometers. When introducing the M549A1 rocket off to the projectile mix, a four-round TOT capability can be achieved at 85% of the range intervals.

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1. INTRODUCTION

At the request of the Advanced Towed Cannon System (ATCAS) Program Manager, the U.S. Army Research Laboratory (ARL) conducted a study that addressed the technical feasibility of a single gun, multiple round, time-on-target (TOT) capability for advanced towed cannon artillery. The ability of cannon artillery to place effective fire on target depends on the method of fire and type of ammunition selected to attack the target. Cannon artillery achieves maximum effect through accurate initial fires and massed fires (Department of the Army 1991). TOT is one example of massed fires. TOT is "the method of firing on a target in which various artillery units and naval gunfire support ships so time their fire as to assure the initial rounds strike the target simultaneously at the time required" (Department of Defense 1986). Typically, TOT fire missions are pre-planned to allow a single round fired from each gun within a battery, battalion, or division to simultaneously impact the same target. The TOT method of fire ensures maximum effectiveness when attacking targets that can easily change their posture (e.g., personnel in the open).

Advances in technology offer an opportunity for cannon artillery weapons to dramatically enhance their effectiveness. Power-assisted elevation and auto-loader mechanisms allow the soldier to load ammunition faster and increase the rate of fire. These enhancements allow a single howitzer to conduct a multiple round TOT mission by rapidly changing quadrant elevation (QE) and firing different charges within the same fire mission. Large differences in the time of flight (TOF) for each trajectory provide the time required to change QE and charge between shots, which will result in the simultaneous impact of all projectiles fired. If a single howitzer can conduct a four-round TOT mission, it can theoretically achieve a TOT effectiveness similar to a four-gun platoon firing a single TOT round from each gun. This report addresses the technical feasibility of a single gun, multiple round, TOT capability for ATCAS.

2. BACKGROUND

2.1 Multiple Round Time on Target

Studies and tests involving the single gun, multiple round, TOT concept have been successfully completed by several organizations using different self-propelled howitzers. In June 1988, the former Human Engineering Laboratory (HEL; now ARL) demonstrated a three-round TOT capability with the 155mm, self-propelled, human factors howitzer test bed (HFHTB). HEL also demonstrated a four-round TOT capability with the HFHTB in June 1991. In July

1991, the Firing Tables Branch (formerly of the Ballistic Research Laboratory) received a request from the Training and Doctrine Command, System Manager-Cannon (TSM-CN) for a multiple round TOT study comparing standard propelling charges with unicharge and liquid propellant (Sowa 1992). The Office of the Project Manager for the Advanced Field Artillery System also requested a similar study (Sowa 1993). In April 1993, ARL demonstrated several four-round TOT missions with the HFHTB and the Vickers Shipbuilding and Engineering Limited, 155mm self-propelled, AS90 howitzer. Also in 1993, the Office of the Project Manager for Paladin demonstrated a four-round TOT capability with the 155mm self-propelled, M109A6 howitzer.

2.2 Advanced Towed Cannon System

At the request of Congress, the Armament, Research, Development, and Engineering Center; the U.S. Army Field Artillery School; the Marine Corps Systems Command; and ARL formed the ATCAS program to conduct studies and tests to support the rationale for the joint operational requirements document (JORD) for a new lightweight, towed, 155mm howitzer. The ATCAS program consists of three test beds: analytical, engineering, and operational. Studies related to the firing platform, system components, firing battery system, precision, accuracy, and force-on-force effectiveness are conducted within the analytical test bed. Controlled experimentation and testing of various prototypes, as well as fabricating and testing of potential product improvements for the existing towed system are conducted within the engineering test bed. Experimentation and testing of various prototypes and potential product improvements operated by selected light forces units are conducted within the operational test bed.

3. OBJECTIVE

Several organizations have thoroughly studied and demonstrated the multiple round TOT capability for self-propelled howitzers. The objective of this study was to determine the technical feasibility of a single gun, multiple round, TOT capability for ATCAS.

4. PROCEDURES

The procedures followed during previous multiple round TOT studies were modified to better fit the characteristics of towed cannon artillery. The study parameters were identified as projectile type, propellant type, howitzer, minimum range of interest, maximum range of interest, impact tolerances (range and time), and minimum time between rounds (TBR). A matrix of

study parameters is given in Table 1. The scope of this study was limited to standard firing table conditions. The minimum TBR, projectile loading restrictions, and projectile mix within a fire mission were varied to determine the maximum benefit to the single gun, multiple round, TOT capability. The measure of effectiveness was the total number of TOT rounds simultaneously delivered on the same target. This was addressed at each range of interest. The summarized results were reported as a percentage of range intervals covered within the range band.

Table 1. Matrix of Study Parameters

	Proj.*	Prop. Chg	How.	Range Band (km)	Range Impact Tol. (m)	Time Impact Tol. (sec)	Mission Cycle Time (sec)	Tube Elev. Rate (mils/sec)	Load Elev. Rest. (mils)
Case 1	M107 M549A1	Std Bag	M198	5-24	0	2	5/5**	15	≤600
Case 2	M107 M549A1	Std Bag	M198	5-24	0	2	10	15	none
Case 3	M107 M549A1	Std Bag	M198	5-24	0	2	5/5	30	≤600
Case 4	M107 M549A1	Std Bag	M198	5-24	0	2	5/5	50	≤600
Case 5	M107 M549A1	Std Bag	M198	5-24	0	2	10	30	none
Case 6	M107 M549A1	Std Bag	M198	5-24	0	2	10	50	none

* Projectile Mix 1 = M107 or M549A1 R-on
 Projectile Mix 2 = M107 and M549A1 R-on
 Projectile Mix 3 = M107, M549A1 R-on and R-off

** Load and ram projectile = 5 seconds
 Load propelling charge, close breech, insert primer = 5 seconds
 Total mission cycle time = 10 seconds

4.1 Rate of Fire

For the earlier studies, constant values were used for the minimum TBR fired.   Since the cannon tube on the current towed howitzer is manually elevated and depressed, a constant TBR was inappropriate for fire missions containing multiple QEs. To account for the difference, this study replaced the constant value for TBR with a function. The function contained information about the speed at which the tube could be moved (tube elevation rate), an elevation restriction for loading projectiles (load elevation restriction), and the time it takes to load the ammunition (mission cycle time).

4.1.1 Tube Elevation Rate

Three different tube elevation rates (TERs) were used in this study. The slowest TER was 15 mils per second. This assumed that the cannon tube was manually elevated and depressed. The other two TERs were 30 mils per second and 50 mils per second. These TERs can be achieved with a power-assisted elevation mechanism.

4.1.2 Load Elevation Restriction

Because of the nature of towed howitzers, the maximum tube elevation for projectile loading was restricted. This was termed the load elevation restriction (LER). Two LERs were used in the study. The first LER was 600 mils. In this case, projectiles could only be loaded at 600 mils or less. If two sequential QEs were above 600 mils, the tube would be depressed to 600 mils for loading. The load restriction applied to the projectile only. That is, the propelling charge and primer could be loaded at any elevation. This study also addressed the enhancement of the multiple round, TOT capability when the LER was eliminated. Therefore, the second LER (LER = none) assumed that projectiles could be loaded at all elevations. This could be accomplished with a loader-assist mechanism.

4.1.3 Mission Cycle Time

The mission cycle time (MCT) data used in this study were extracted from empirical test results from a rate-of-fire study conducted by the former HEL (Paragallo and Dousa 1979). Paragallo and Dousa determined realistic rates of fire for one Soviet (122mm) and two U.S. (105mm and 155mm) towed howitzers to allow system analysts to accurately assess current weapon system capabilities and to provide a data base to predict future weapon performance. On average, the total mission cycle time for loading and ramming the projectile, loading the

propelling charge, closing the breech, and inserting the primer for the U.S. 155mm towed howitzer was approximately 10 seconds. Projectile loading and ramming required approximately 5 seconds. Loading the propelling charge, closing the breech, and inserting the primer also required approximately 5 seconds.

In this TOT study, cases with no loading restriction had an MCT of 10 seconds. It was assumed that all loading occurred concurrently with tube movement. In cases with an LER, the MCT was split into two times (MCT1 and MCT2). MCT1 represented the time required to load and ram the projectile (5 seconds). After the tube was depressed to the maximum loading elevation, the projectile was loaded and rammed while the tube was stationary. MCT2 represented the time required to load the propelling charge, close the breech, and insert the primer (5 seconds). Since the LER did not apply to the propelling charge, breech, or primer, this portion occurred concurrently with moving the tube from the maximum loading elevation to the target QE.

4.2 Projectile Mix

Three options for projectile mix were considered. The first option limited a given fire mission to a single type of high explosive projectile. For example, all projectiles within the mission were either M107 or M549A1 fired rocket on (R-on). The second option permitted a mix of M107 and M549A1 R-on projectiles within the same mission. The last option permitted a mix of M107, M549A1 R-on, and M549A1 fired rocket off (R-off). Although the M549A1 R-off is not contained in current field computers, the aerodynamic and ballistic data were available for analysis.

4.3 Range Band

The range band used for this study was between 5 and 24 kilometers. Using standard firing table conditions, the extreme short and long ranges outside this range band could only be engaged by a limited number of ballistic solutions; therefore, they were not included in this study. The range band was divided into 20 1-kilometer range intervals. The trajectory analysis was conducted for each of the 20 range intervals.

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4.4 Impact Tolerances

The range impact tolerance was 0 meters. Therefore, all trajectories were computed to the identical range. The time impact tolerance was 2 seconds. Thus, the maximum time between the first impact and the last impact was 2 seconds. After the impact of the initial round of a fire mission, target posture changes rapidly. Once a target is hardened or better protected, the effectiveness of subsequent rounds decreases dramatically. Soft targets typically need 3 to 4 seconds to become hard targets. The difference between this time and the time impact tolerance used in the study (2 seconds) would account for the effects of any unknown, nonstandard conditions that could affect TOF.

4.5 Trajectory Computation, Analysis, and Selection

After the procedures were modified and the parameters were selected, trajectory data were computed for each of the 1-kilometer intervals in the range band of interest (5 to 24 km). The study did not address ranges between the 1-kilometer intervals. All trajectories were computed with the Firing Tables Branch, General Trajectory Model, Version 3 under standard firing table conditions. This is the same model implemented in the battery computer system (BCS). The model is based on the equations of motion for a modified point mass trajectory (Lieske and Reiter 1966). The aerodynamic and ballistic data for the M107 and M549A1 projectiles are contained in fire control input documents FCI 155-AM-B and FCI 155-AO-0, respectively.

After the trajectory data were computed, ballistic solutions with QEs between 200 and 1250 mils were selected for consideration for each range interval (within the range band). The total number of ballistic solutions as a function of projectile type is shown for each range interval in Figure 1. The firing solutions were then sorted by time of flight. The combination of firing solutions meeting the "time to impact tolerance" criterion for a given range was then counted.

The computation of the minimum time required to load ammunition and change QE created the most complexity in the study. Four different equations were used to handle the various combinations of TER and LER. If the study case had no LER (i.e., ammunition could be loaded at all elevations), the difference between the two sequential QEs was divided by the TER to determine the minimum TBR. This is shown in Equation 1. If a study case had an LER and the first QE was above the LER while the subsequent QE was below the LER or if both QEs were below the LER, Equation 1 was also used for the minimum TBR. It was determined that loading would take place concurrently with the change in elevation.

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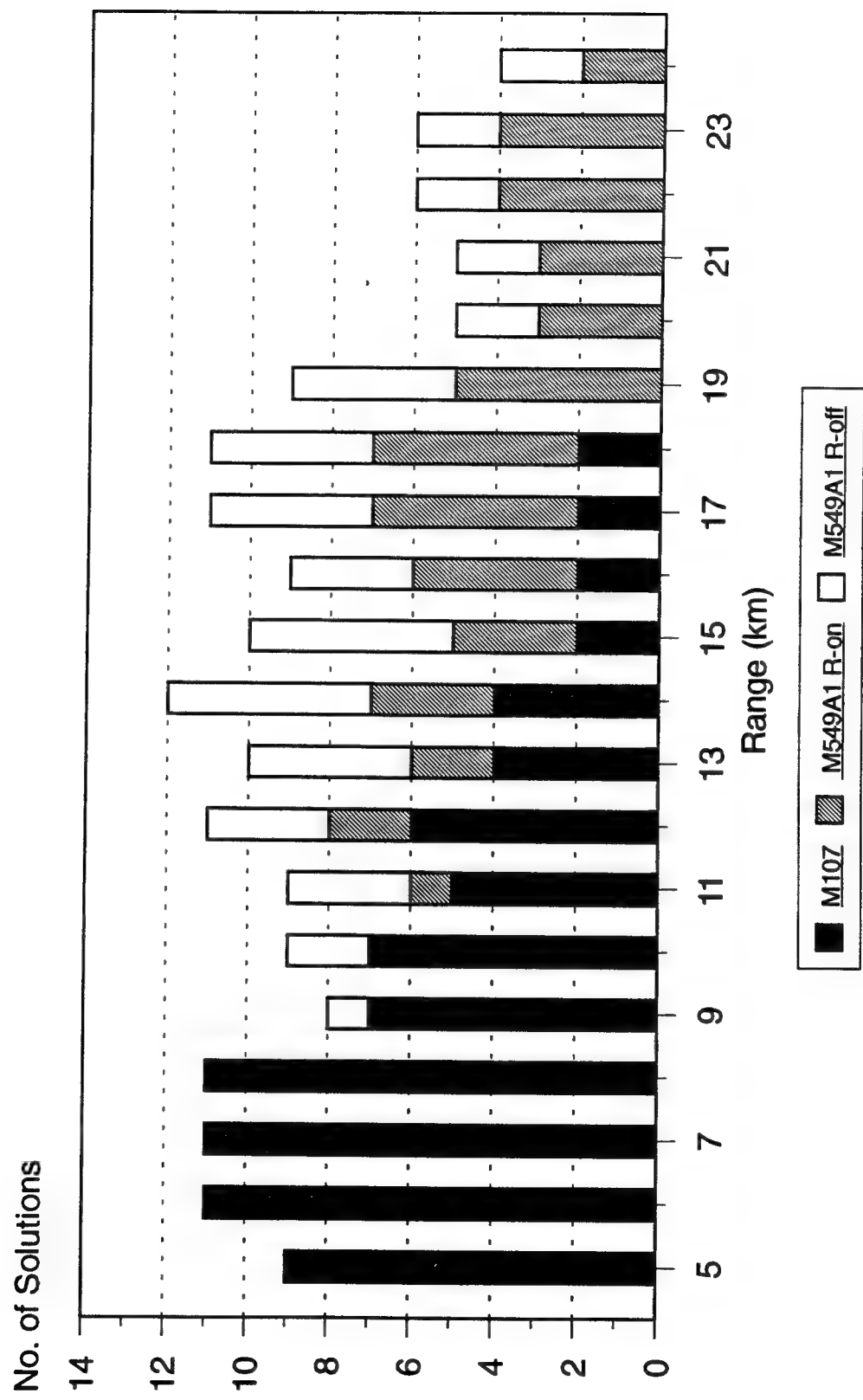# Total Number of Ballistic Solutions
Standard Conditions

Figure 1. Total Number of Ballistic Solutions, Standard Conditions.

$$TBR = \frac{(QE_{n+1} - QE_n)}{TER} \tag{1}$$

For the study cases with high TERs, the time needed to change QE was often less than the mission cycle time. In this case, the mission cycle time was used as the minimum TBR. This is shown in Equation 2.

$$if \qquad \frac{(QE_{n+1} - QE_n)}{TER} < MCT$$

$$\tag{2}$$

$$then \qquad TBR = MCT$$

When a study case had an LER and two sequential QEs above the load elevation, the mission cycle time was split into two values. MCT1 represented the time required to load and ram the projectile. MCT2 represented the time required to load the propelling charge, close the breech, and insert the primer. The minimum TBR was determined by calculating the length of time required to depress the tube from the first QE to the load elevation, load and ram the projectile, and elevate the tube to the subsequent QE. The difference between the first QE and the load elevation was divided by the TER. This value was added to the time required to load and ram the projectile (MCT1) as defined earlier. This accounts for loading and ramming the projectile while the tube was stationary. The difference between the subsequent QE and the load elevation was also divided by the TER. If this time was greater than the time required to load the propelling charge, close the breech, and insert the primer (MCT2), it was added to the previous value. If MCT2 was greater, it was added to the previous value. This accounts for loading the propelling charge, closing the breech, and inserting the primer concurrently with moving the tube to the subsequent QE. These calculations are shown in Equations 3 and 4.

$$if \qquad \frac{(QE_{n+1} - LER)}{TER} < MCT2$$

$$\tag{3}$$

$$then \qquad TBR = \frac{(QE_n - LER)}{TER} + MCT1 + MCT2$$

$$\text{if} \qquad MCT2 < \frac{(QE_{n+1} - LER)}{TER}$$

$$(4)$$

$$\text{then} \qquad TBR = \frac{(QE_n - LER)}{TER} + MCT1 + \frac{(QE_{n+1} - LER)}{TER}$$

5. RESULTS

The single gun, multiple round, TOT capability was determined at the 20 1-kilometer intervals in the 5- to 24-kilometer range band for each of the six possible combinations of TER (15, 30, 50 mils/sec) and LER (600 mils, none). This determination was made for three projectile mix options (M107 or M549A1 R-on; M107 and M549A1 R-on; M107, M549A1 R-on, and R-off). The TOT capability results for each of the six combinations of TER and LER are given in Figures 2 through 7.

The most restrictive set of parameters in this study were contained in Case 1. It had the lowest TER (15 mils per second) and an LER of 600 mils. This was the closest representation of the capabilities of the current 155mm, towed, howitzer (M198). When the projectile mix was restricted to a single type (M107 or M549A1 R-on), a three-round TOT capability was achieved at 6 of 20 range intervals (30%) in the range band. When the projectile mix was changed to M107 and M549A1 R-on, the occurrence of the three-round TOT capability increased to eight range intervals (40%). When the M549A1 R-off was introduced to the mix, this occurrence again increased to nine range intervals (45%).

In Case 2, the TER was held at 15 mils per second; however, the LER was eliminated. Projectiles were loaded at all QEs. When the projectile mix was restricted, a three-round TOT capability was achieved at ten range intervals (50%) and a four-round TOT capability was achieved at two range intervals (10%). When the projectile mix was changed to M107 and M549A1, the occurrence of the three-round TOT capability increased to 12 range intervals (60%), and the four-round TOT capability increased to four range intervals (20%). When the M549A1 R-off was introduced to this mix, the occurrence of the three-round TOT capability again increased to 13 range intervals (65%), and the four-round TOT capability increased to five range intervals (25%). This was an improvement over Case 1.
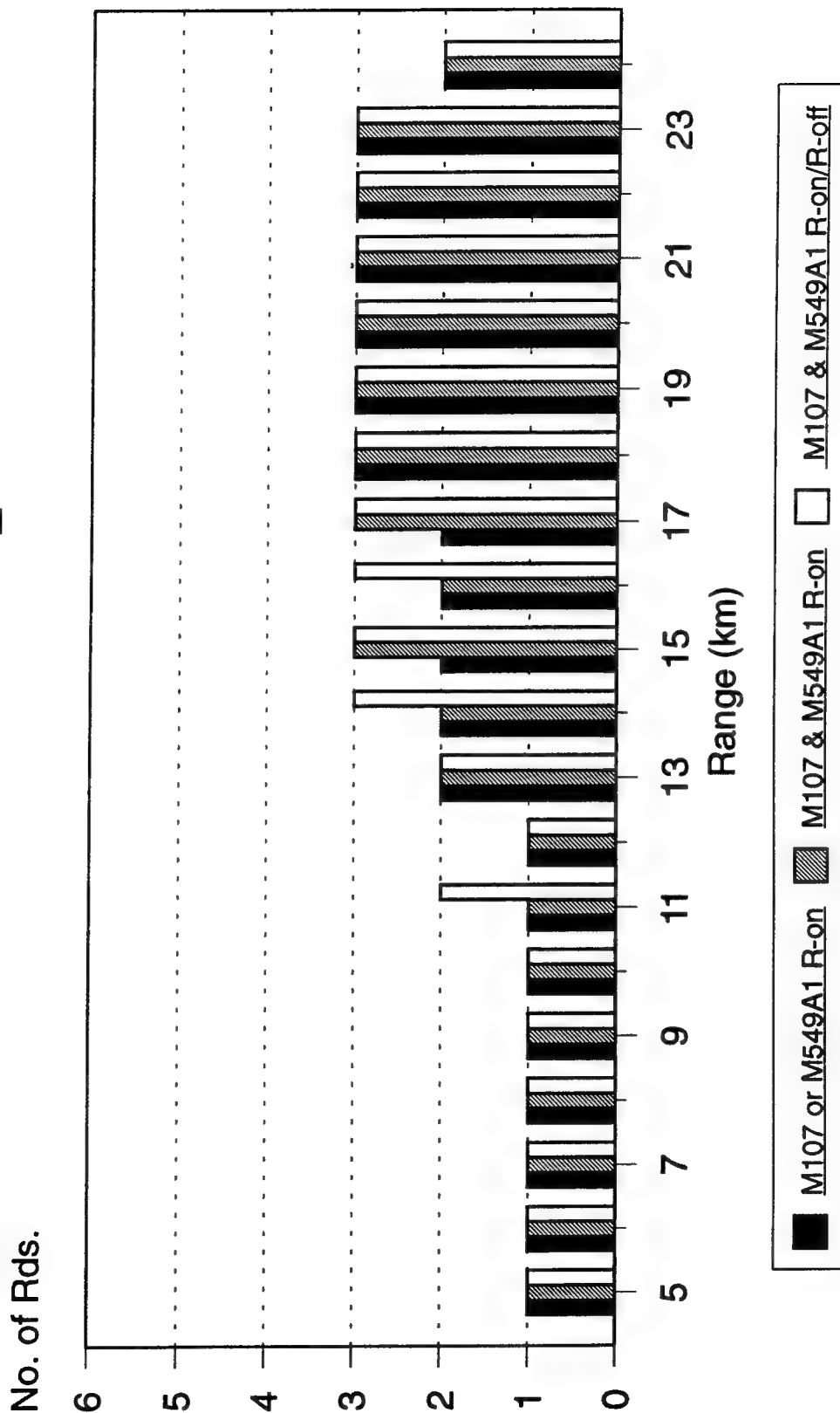
Figure 2. Case 1, TER = 15 mils/sec, LER ≤ 600 mils.

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Figure 3. Case 2, TER = 15 mils/sec, LER = None.

Case 3
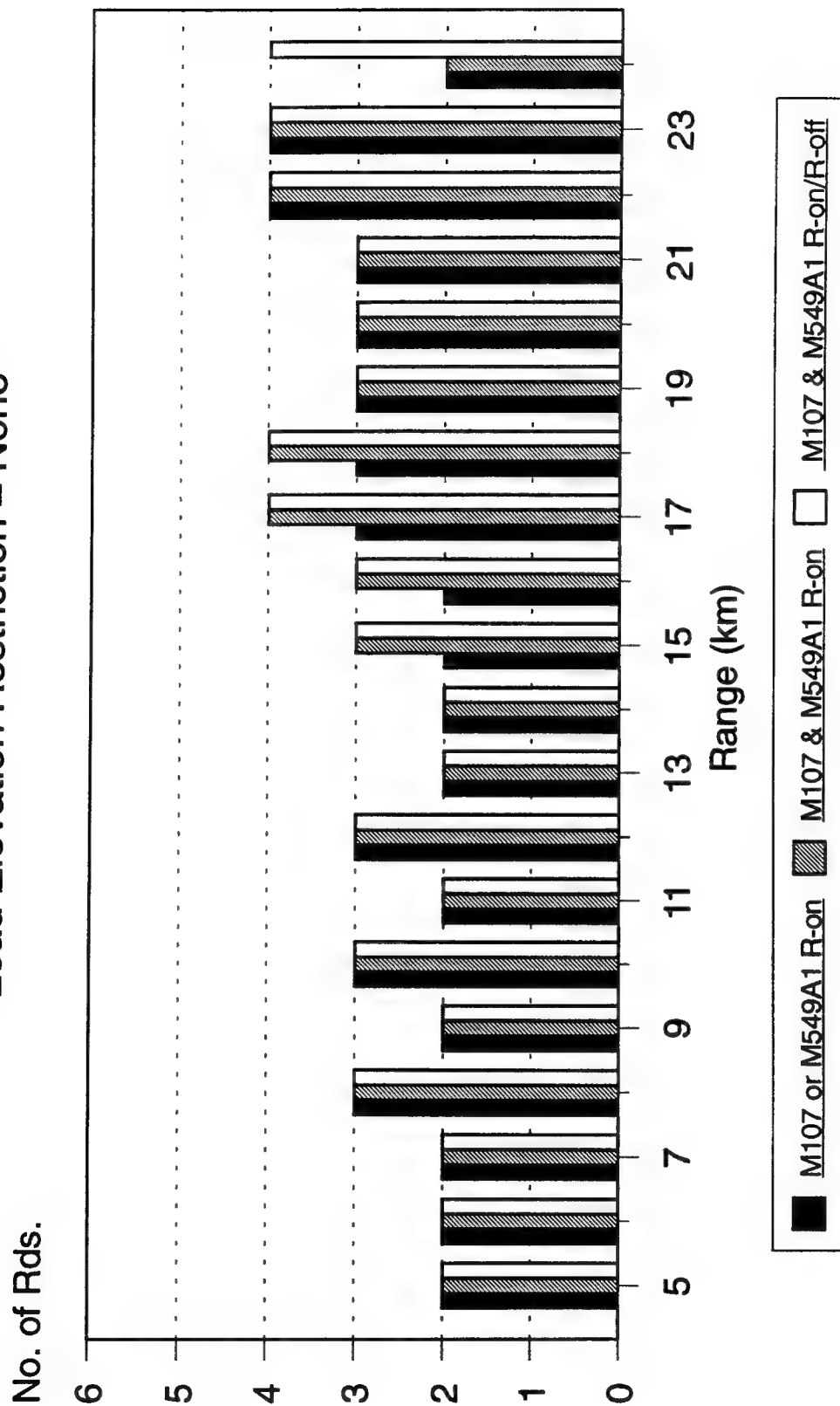## Tube Elevation Rate = 30 mils/sec
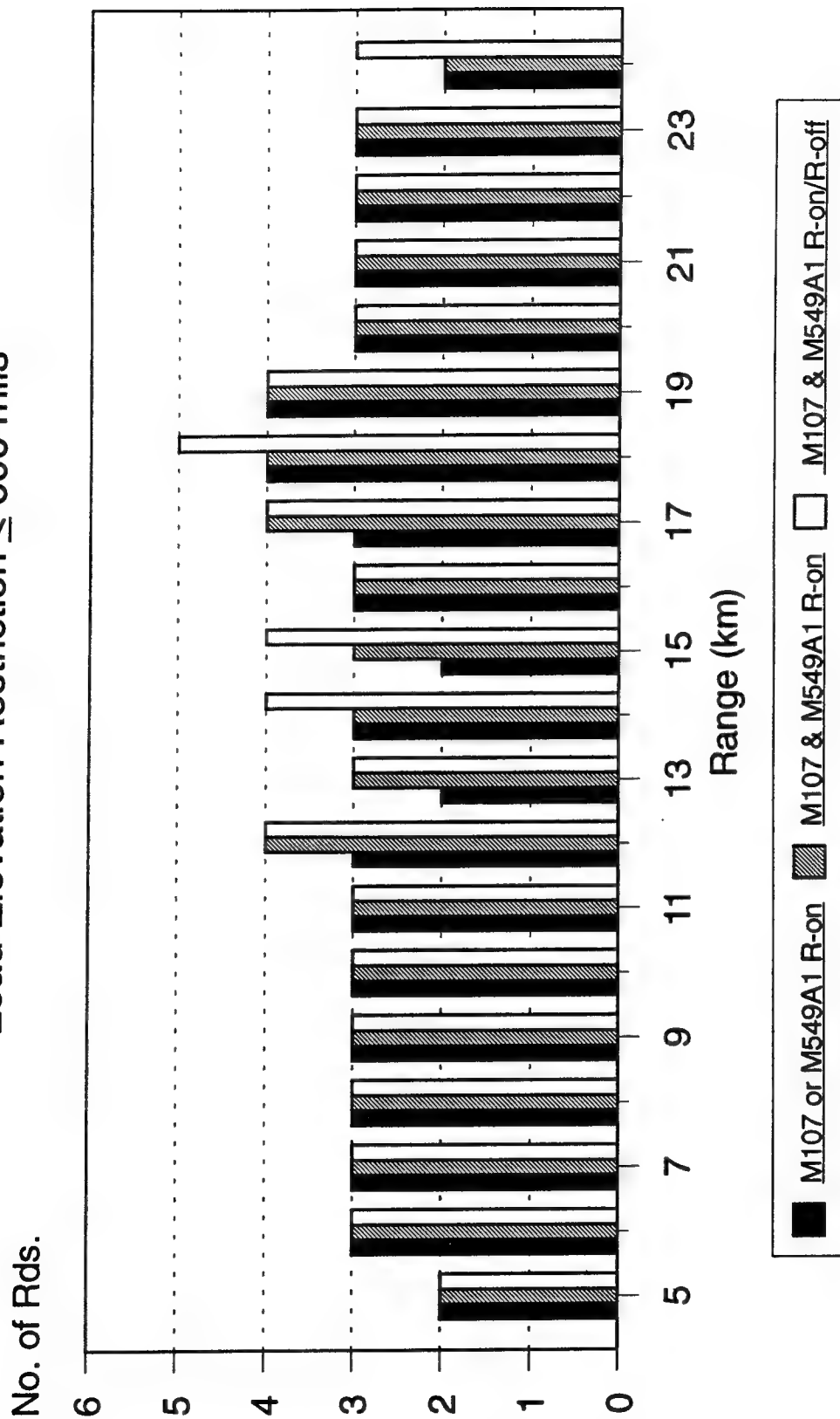## Load Elevation Restriction ≤ 600 mils

Figure 4. Case 3, TER = 30 mils/sec, LER ≤ 600 mils.

Case 4
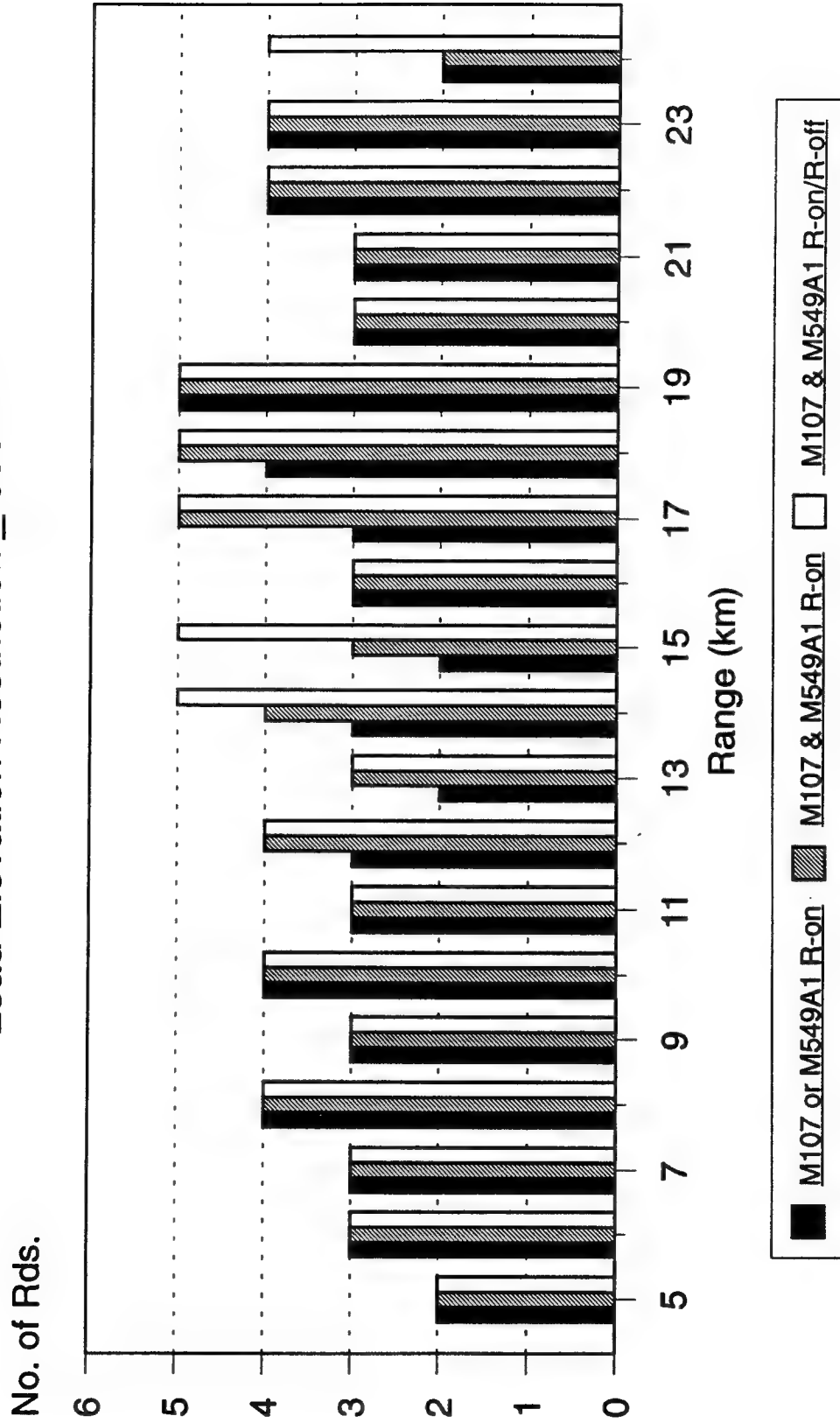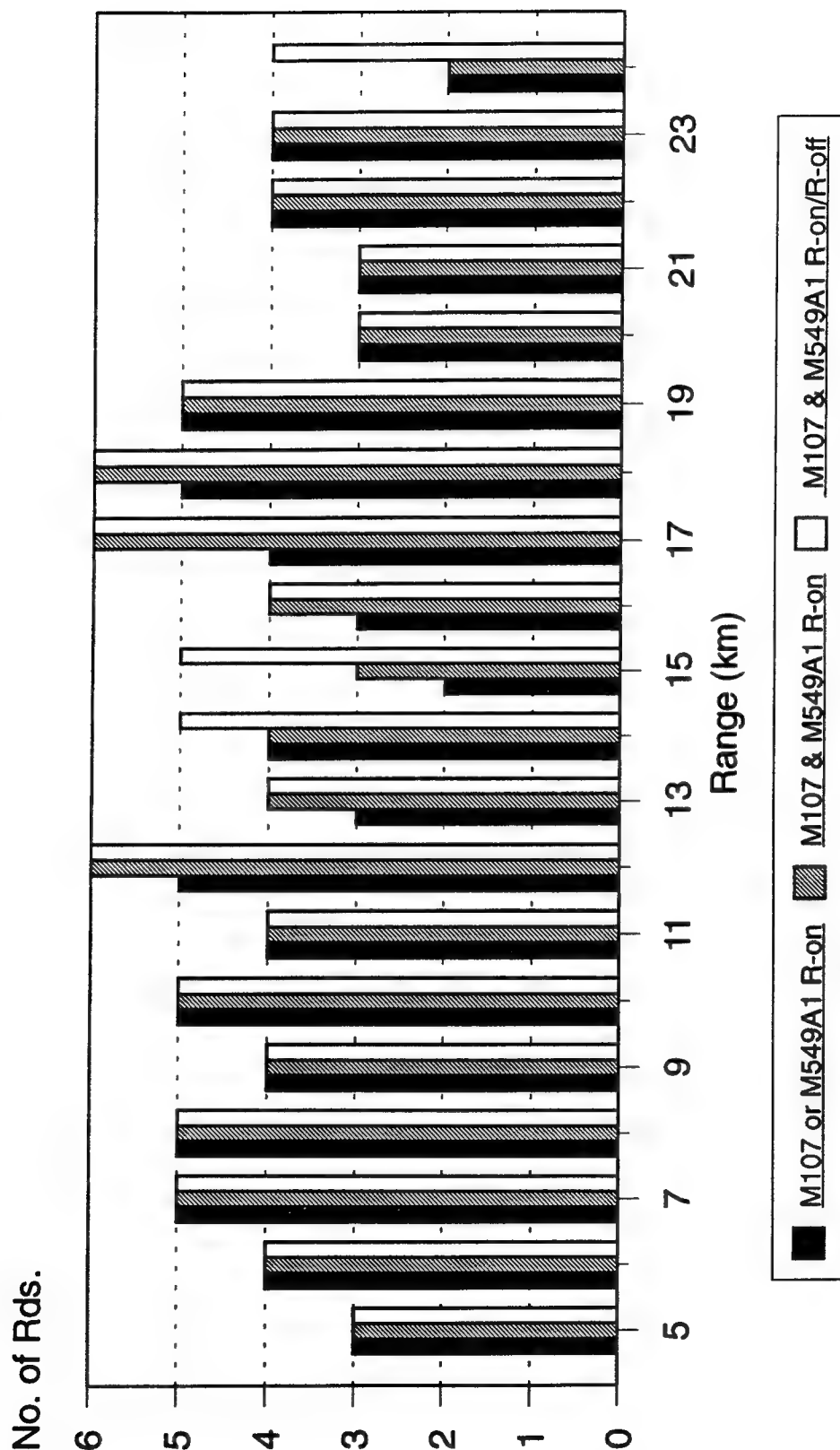## Tube Elevation Rate = 50 mils/sec
Load Elevation Restriction $\leq$ 600 mils

Figure 5. Case 4, TER = 50 mils/sec, LER< 600 mils.

Figure 6. Case 5, TER = 30 mils/sec, LER = None.
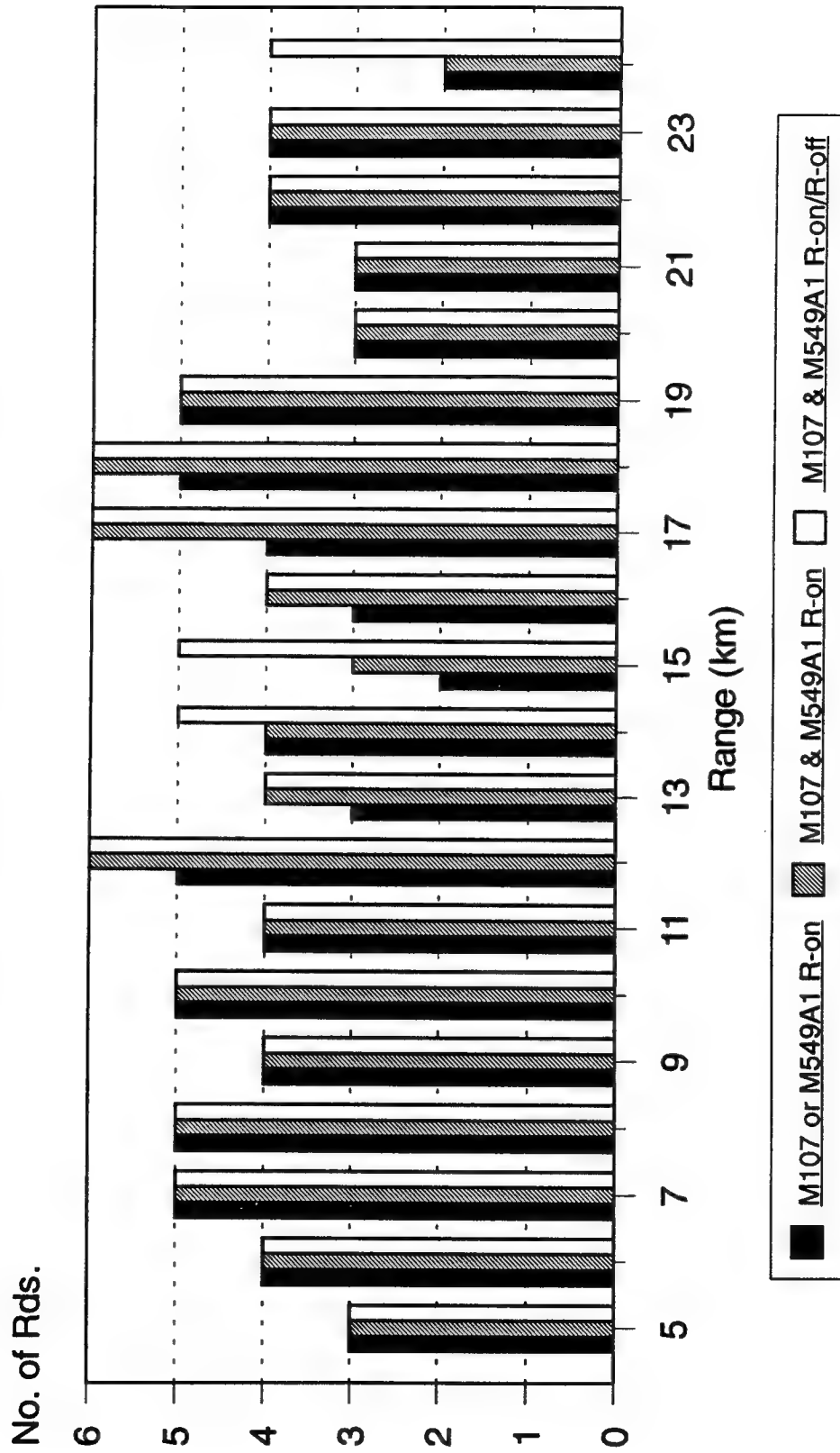
Figure 7. Case 6, TER = 50 mils/sec, LER = None.

In Case 3, the TER was increased to 30 mils per second, and the LER was 600 mils. When the projectile mix was restricted, a three-round TOT capability was achieved at 16 range intervals (80%), and a four-round TOT capability was achieved at two range intervals (10%). When the mix restriction was removed, the occurrence of the three-round TOT capability increased to 18 range intervals (90%), and the four-round capability increased to four range intervals (20%). When the M549A1 R-off was introduced to the mix, the three-round TOT capability increased to 19 range intervals (95%), and the four-round TOT capability increased to six range intervals (30%). In addition, the mix including the M549A1 R-off also reached a five-round TOT capability at one range interval (18 km). This was an improvement over Case 2.

In Case 4, the TER was increased to 50 mils per second, and the LER was held at 600 mils. With a restricted projectile mix, a three-round TOT capability was achieved at 16 range intervals (80%), and the four-round TOT capability was achieved at six range intervals (30%). Also, a five-round TOT capability was achieved at one range interval (19 km). When the mix restriction was removed, the three-round TOT capability increased to 18 range intervals (90%), the four-round capability increased to nine range intervals (45%), and the five-round capability increased to three range intervals (15%). When the M549A1 R-off was introduced to the mix, the three-round TOT capability increased to 19 range intervals (95%), the four-round TOT capability increased to 11 range intervals (55%), and the five-round TOT capability increased to five range intervals (25%). Compared to Case 3, the range coverage for the four- and five-round TOT capability increased; however, the range coverage for the three-round capability remained the same. This was consistent for each projectile mix.

In Case 5, the TER was 30 mils per second, and the LER was eliminated. With a projectile mix restriction, a three-round TOT capability was achieved at 18 range intervals (90%), a four-round TOT capability was achieved at 13 range intervals (65%), and a five-round TOT capability was achieved at six range intervals (30%). By eliminating the mix restriction, the three-round capability increased to 19 range intervals (95%), the four-round TOT capability increased to 15 range intervals (75%), and the five-round TOT capability increased to seven range intervals (35%). In addition, a six-round TOT capability was achieved at three range intervals (15%). When the M549A1 R-off was introduced, the three-round capability was achieved at all 20 range intervals (100%). The four-round TOT capability increased to 17 range intervals (85%), the five-round TOT capability increased to nine range intervals (45%), and the six-round TOT capability remained the same. This set of parameters achieved the maximum single gun, multiple round, TOT capability for each projectile mix.

In Case 6, the TER was increased to 50 mils per second, and the LER was eliminated. This set of parameters produced results that were identical to those of Case 5. With the combination of a high TER and no load restriction, the mission cycle time (10 seconds) became the restricting factor.

The results for each of the three projectile mixes are summarized in Figures 8 through 10. For each projectile mix, the percentage of range coverage is plotted as a function of the number of TOT rounds for each combination of TER and LER.

In addition, a four-round TOT summary is provided in Figure 11. For the four-round TOT capability, the percentage of range coverage is plotted as a function of projectile mix for each combination of TER and LER. It should be noted that the relatively short time of flight to 5 kilometers prevented a four-round TOT capability at that range. Also, the small differences in TOF for the limited number of ballistic solutions at 20 and 21 kilometers prevented a four-round TOT capability at those ranges.

6. CONCLUSIONS

The conclusions listed below are limited to the scope of this study.

- Eliminating the LER produces a significant enhancement of the single gun, multiple round, TOT capability.

- With the ability to load at all elevations, TERs of 30 mils per second and 50 mils per second produce the same single gun, multiple round, TOT capability.

- With the ability to load at all elevations and a TER of 30 mils per second, a four-round TOT capability can be achieved at 65% of the 1-kilometer range intervals between 5 and 24 kilometers when the projectile mix is restricted within a fire mission (M107 or M549A1 rocket on).

- A howitzer with the same loading and elevation capabilities plus the ability to shoot a mixture of M107 and M549A1 (rocket on) within the same fire mission can achieved a four-round TOT capability at 75% of the range intervals between 5 and 24 kilometers.
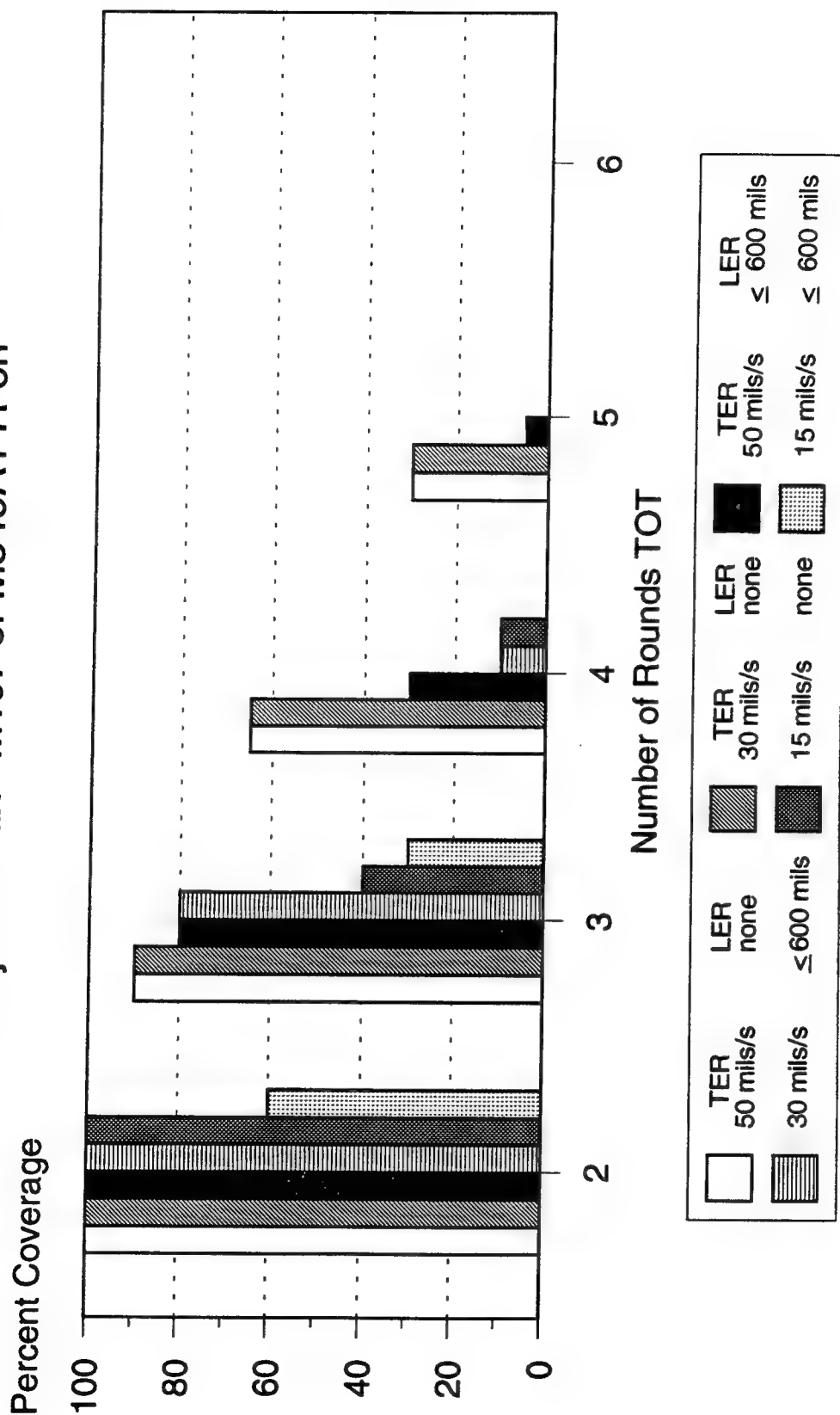
Figure 8. Multiple Round TOT, Percent Range Coverage Summary, Projectile Mix - M107 or M549A1 R-on.

Multiple Round TOT
Percent Range Coverage Summary (5 km to 24 km)
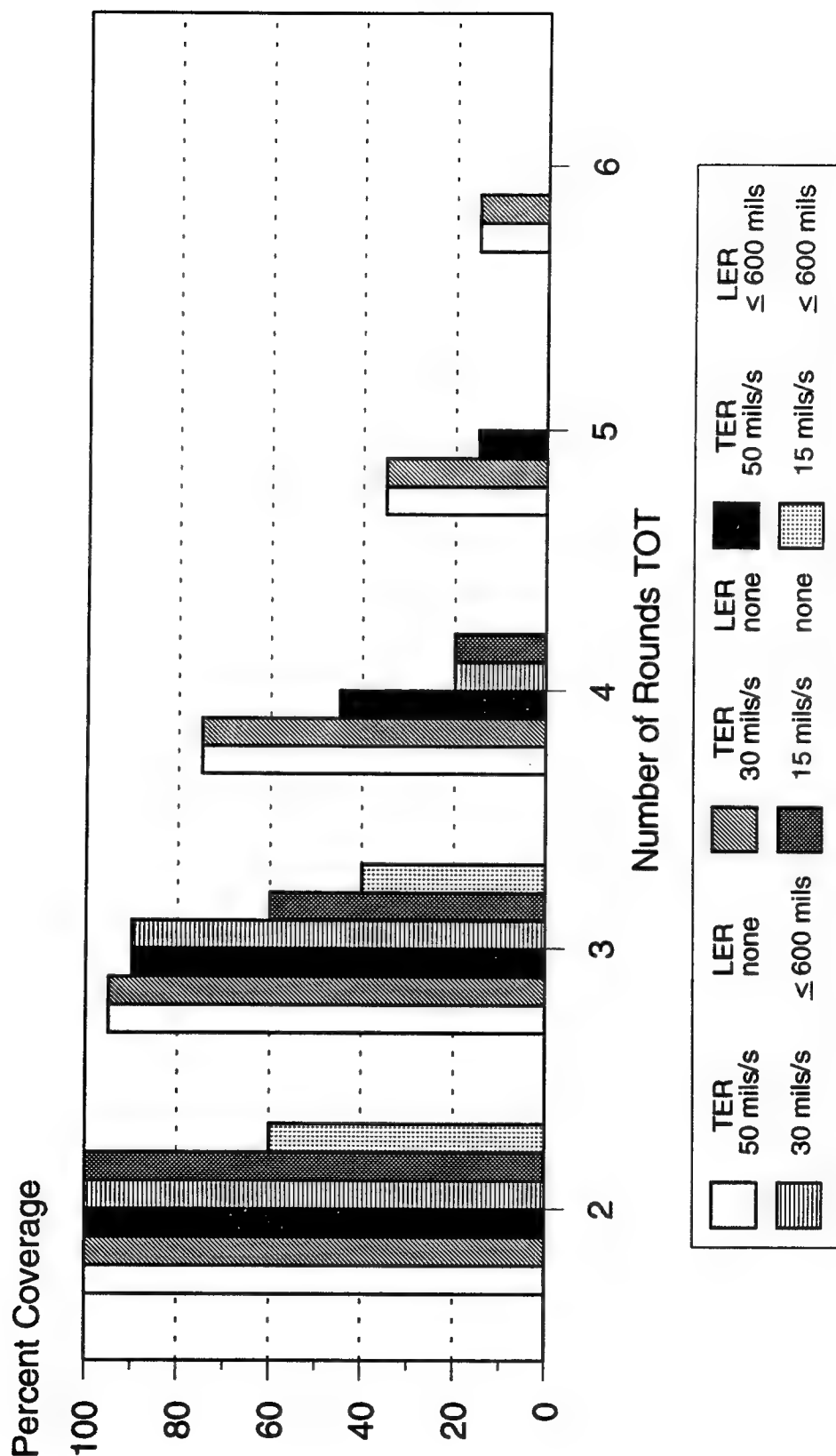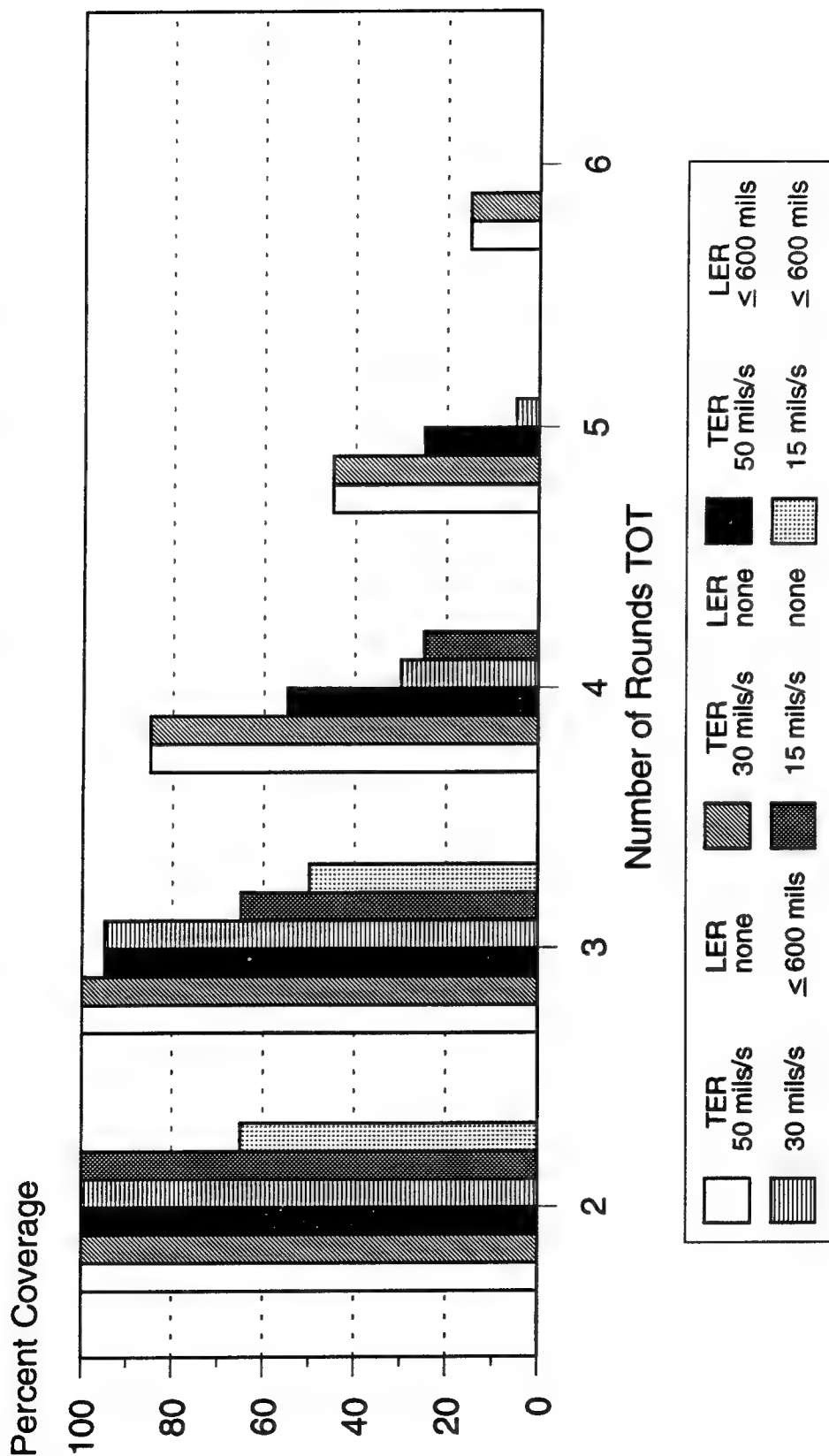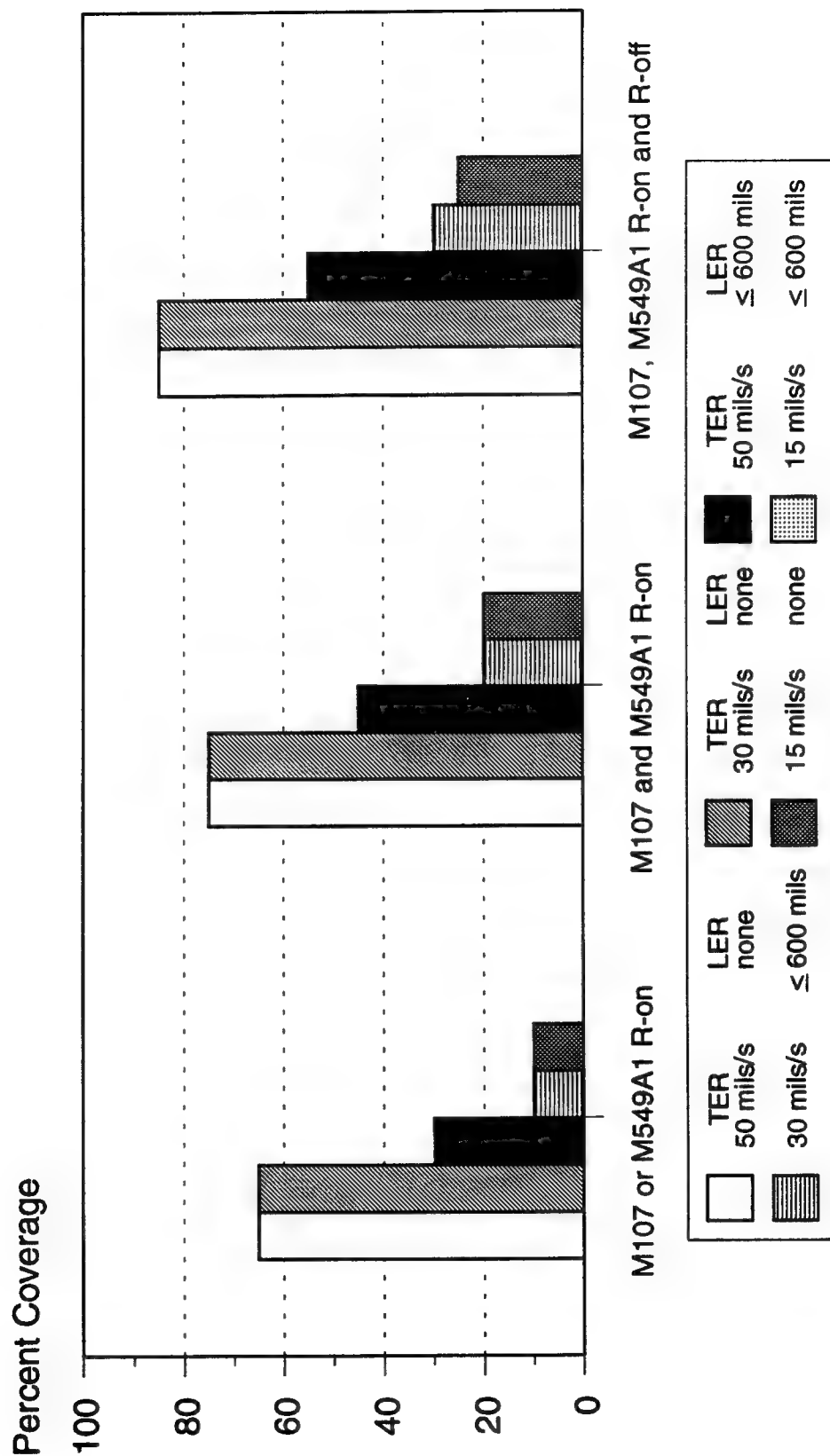Projectile Mix - M107 and M549A1 R-on.

Figure 9. Multiple Round TOT, Percent Range Coverage Summary, Projectile Mix - M107 and M549A1 R-on.

Figure 10. Multiple Round TOT, Percent Range Coverage Summary, Projectile Mix - M107, M549A1 R-on and R-off.

Figure 11. Four-round TOT, Percent Range Coverage Summary.

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- When the M549A1 rocket off is introduced to the projectile mix, a four-round TOT capability can be achieved at 85% of the range intervals.

- The relatively short TOF to 5 kilometers and the small differences in TOF for the limited number of ballistic solutions at 20 and 21 kilometers prevented a four-round TOT capability at those ranges. Therefore, the maximum achievable coverage of a four-round TOT capability between 5 and 24 kilometers is 85% for the projectile mixes considered in this study.

- Before allowing a mix of projectile types within a fire mission, the user should address the increased burden on the towed howitzer section.

- At the time of publication, the production of Projectile, 155mm, HE, M795 was being planned. The M795 is an unassisted high explosive projectile that can be fired with propelling charges M3A1, M4A2, M119A2, and M203A1. The range coverage of the M795 would be similar to the range coverage of the M549A1 R-off to 22.5 km. In addition, the M795 would add to the total number of ballistic solutions at the shorter ranges. The M795 aerodynamic and ballistic data required for trajectory computations have already been implemented into BCS, Version 9. The enhancement of the multiple round TOT capability with a mixture of M795 and M549A1 R-on should be addressed in a subsequent study.

- This study only addresses the technical feasibility of a single gun, multiple round, TOT capability for advanced towed cannon artillery. Since the optimum charge and trajectory are not being selected for every range, the potential decrease in delivery accuracy must be addressed. Longer response times and increased vulnerability are also a concern. Force-on-force modeling should be used to determine the military value added for this technique.

7. REFERENCES

Department of Defense. "Dictionary of Military and Associated Terms." Joint Chiefs of Staff (JCS) Publication 1, Washington, DC, 1 January 1986.

Department of the Army. "Tactics, Techniques, and Procedures For Observed Fire." Field Manual, FM 6-30, Headquarters, Washington, DC, 16 July 1991.

Lieske, R.F., and Reiter, M. L. "Equations of Motion for a Modified Point Mass Trajectory." BRL Report No. 1314, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, March 1966. (AD 485869)

Paragallo, F.R., and Dousa, W.J. " U.S. Army Human Engineering Laboratory Rate of Fire Study." HEL Technical Memorandum 9-79, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, June 1979.

Sowa, A. J., "Target Coverage with 4-Round Time-on-Target." Briefing package for BRL/Ft. Sill Day, Firing Tables Branch, Aberdeen Proving Ground, Maryland, 14 January 1992.

Sowa, A. J., "Investigation of Single Gun Time-on-Target Missions Leading to a Basis for Determining Muzzle Velocity Zoning Solutions for the Regenerative Liquid Propellant Gun." FTB-IR-1, Firing Tables Branch, Aberdeen Proving Ground, Maryland, July 1993.

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